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CHARACTERIZATION OF A TUNABLE UV LASER SOURCE AT 308 NM FOR OZONE SPECTROSCOPY

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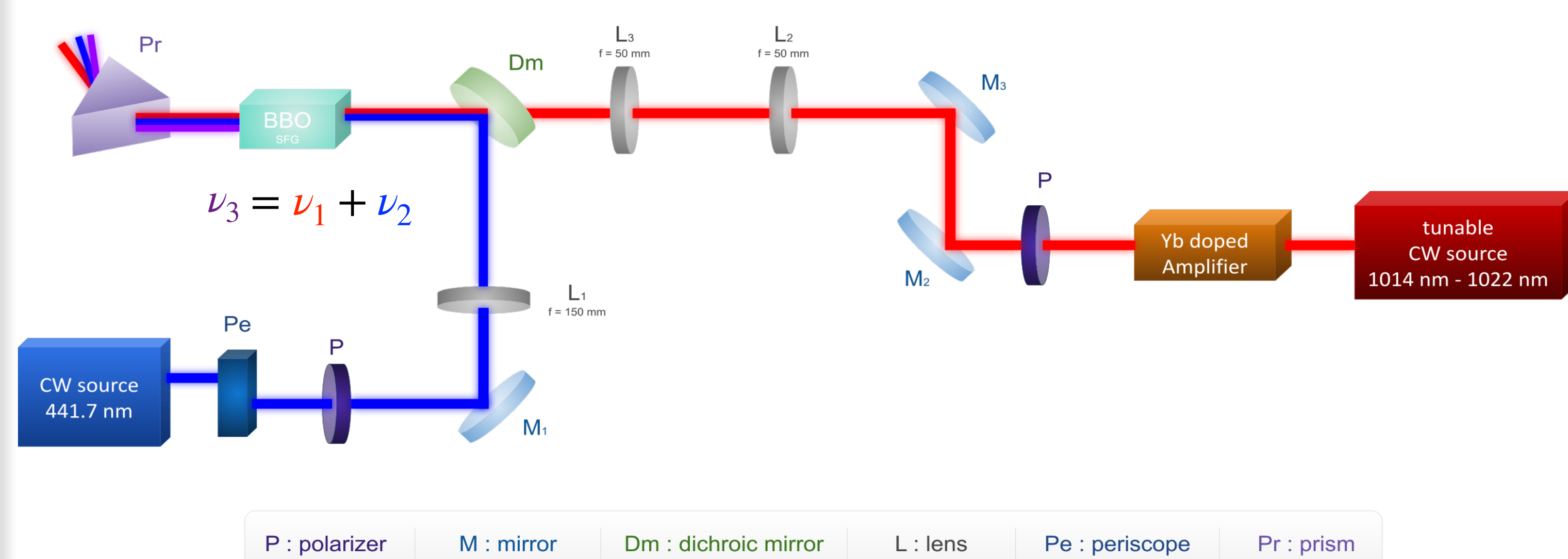
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Context

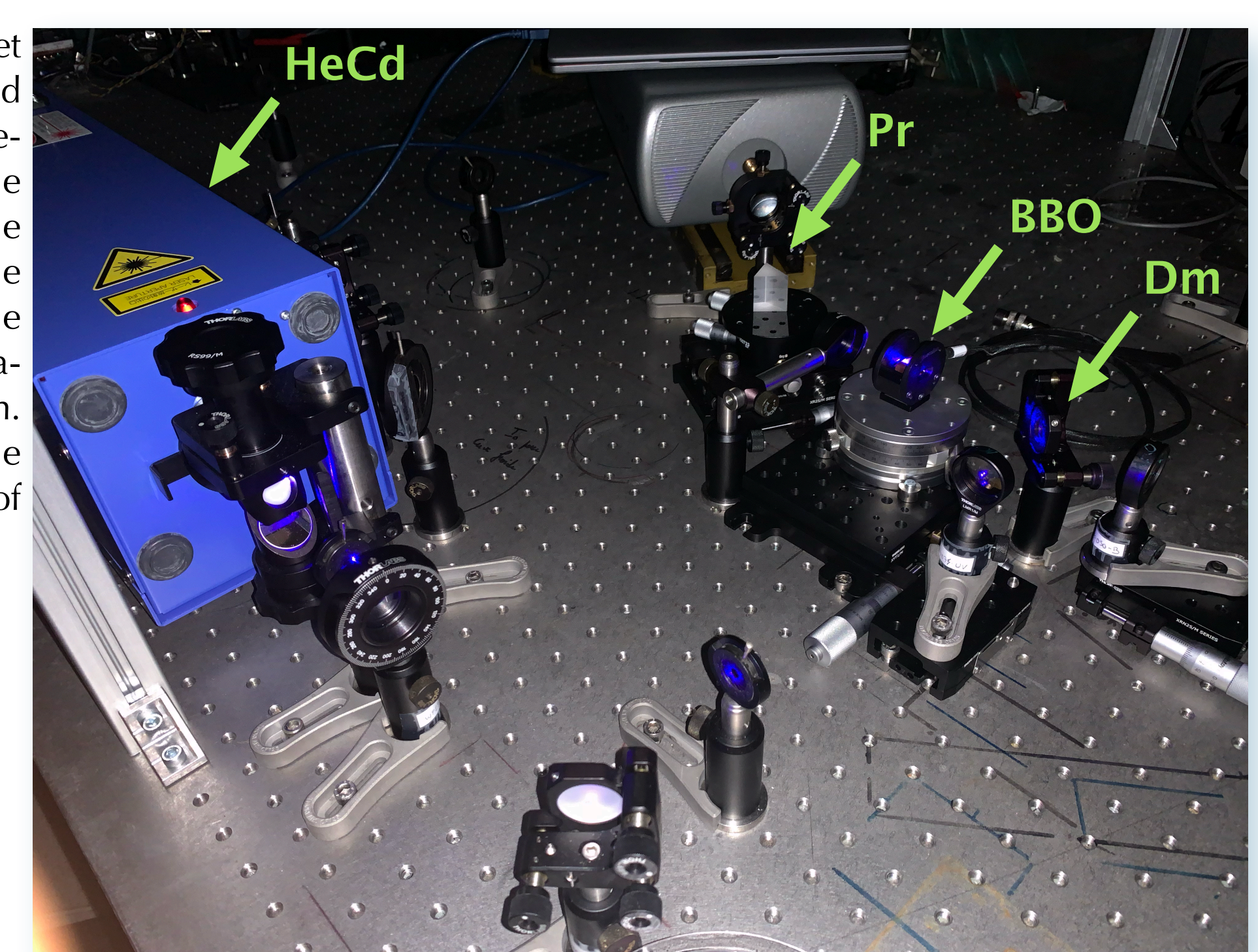
Environmental sciences demand ever more accurate data for the monitoring of the state and the evolution of the Earth system. Ozone is a key molecule in the atmosphere and plays an important role for atmospheric composition and climate change [1]. Efforts are under way to tighter link its atmospheric detection to the recognized standards of the SI [2], but issues in the spectroscopic detection of atmospheric ozone are known to persist. Recent studies suggest that recommended cross sections may be biased by a few percent [3] and opposite trends in the global tropospheric ozone burden derived from satellite instruments (e.g. OMI or TROPOMI operating in the UV versus IASI in the IR) have been observed [4].

Here we propose to improve the ozone absorption data in a spectral window between 308 nm and 318 nm of the Huggins bands using laser spectroscopy. The window is used by ground based (ozone LIDAR, Brewer and Dobson photometers) and satellite (OMI, e.g.) atmospheric remote sensing platforms. Tunable lasers in this wavelength range are rare and we are developing two tunable sources, based on sum frequency generation (SFG) in non-linear optical crystals: one largely tunable source (308 nm - 318 nm) and one narrow band source dedicated for investigations at the LIDAR wavelength of 308 nm. Here, we present a first characterization of the narrow source at 308 nm.

Set up of a SFG laser source at 308 nm



Photography of the set up showing the HeCd laser in blue, the re-combination of the two laser beams on the dichroic mirror, the optical crystal and the prism for the separation of the UV beam. (Abbreviations, are given in the legend of the scheme of the left)



The sum frequency generation (SFG) is realized using two distinct light sources that are injected into a 10 mm long BBO crystal:

- a continuous-wave (cw) helium-cadmium (HeCd) laser (Kimmon), emitting blue light (BL) at a wavelength of 441.7 nm with a steady power output of 159 mW.
- and a lower power (~ 10 mW) cw tunable external cavity diode laser (ECDL, New Focus) emitting infrared (IR) light, tunable between 1014 nm and 1022 nm.

The initial IR power was insufficient for our purposes. To address this, we utilize a Ytterbium-doped fibre amplifier developed by us (LP2N), which operates in the >1014 nm range. It boosts the IR laser power to about 275 mW.

Laser power

The SFG laser power (P_3) can be estimated from the following formula [5] :

$$P_3 = \Gamma_{SFG} P_1 P_2$$

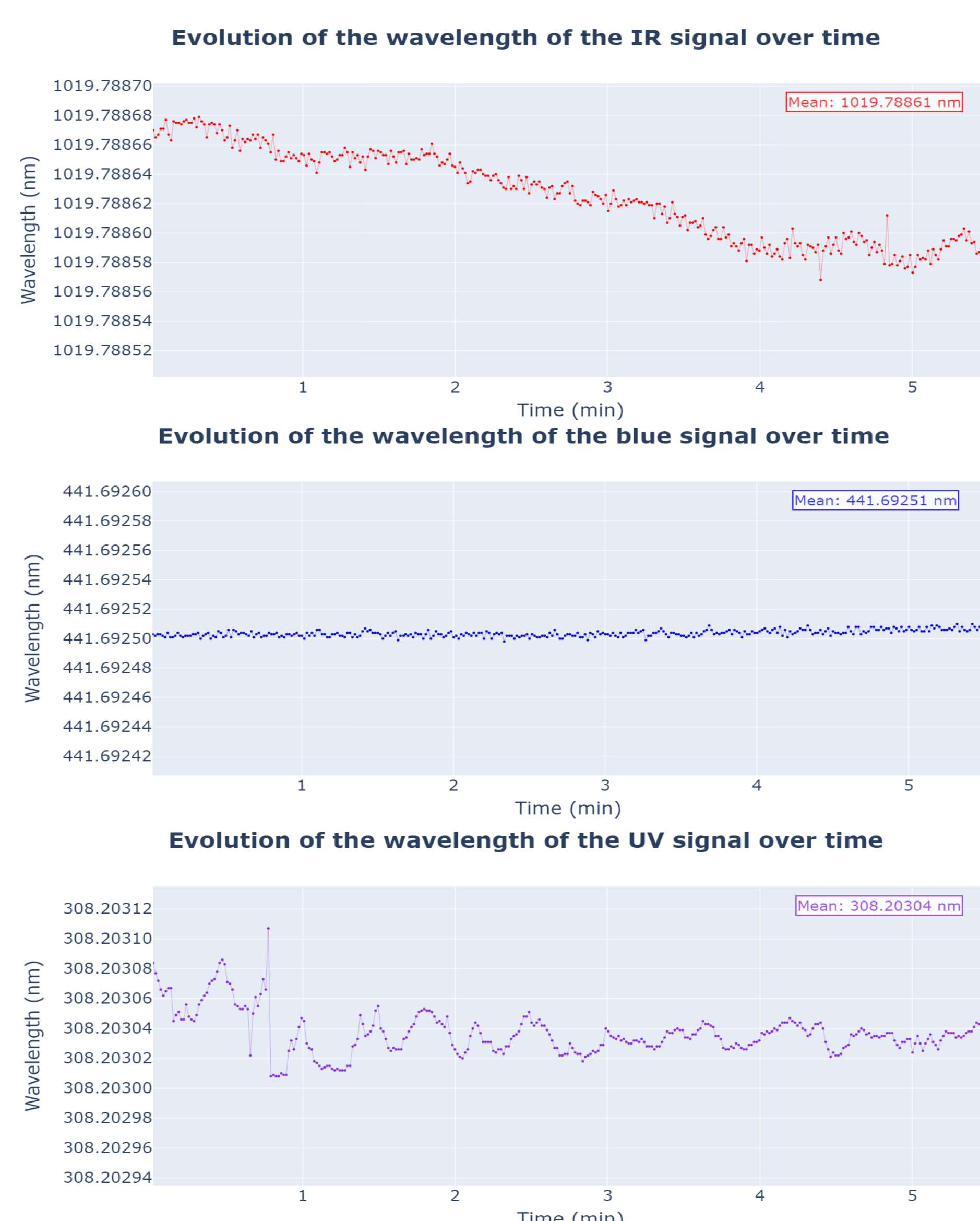
$$\Gamma_{SFG} = K_{SFG} \cdot \left(\frac{l_c^2}{w_1^2 + w_2^2} \right) \cdot e^{(-\alpha_3 \cdot l_c)} \cdot G_{SFG}$$

Labels in diagram: power of the IR signal (P_1), power of the blue signal (P_2), absorption in the crystal for UV wavelength (α_3), length of the crystal (l_c), waist of the IR beam (w_1), waist of the blue beam (w_2).

where P_1 and P_2 , are the IR and blue laser powers, respectively, and the efficiency coefficient Γ_{SFG} depends on the beam waists (w_1, w_2), the crystal length l_c , the absorption coefficient in the crystal (α_3), a constant K_{SFG} given by the electromagnetic properties (refractive indices, vacuum wavelengths, effective non-linear polarization coefficient) and a geometric factor G_{SFG} , describing the focusing conditions and the beam overlap.

Using input powers of 200 mW and 100 mW, respectively, we calculate $P_3 \approx 13 \mu\text{W}$. We have used a Si-photodiode detector (Oriol) with calibrated spectral response curve in order to determine the UV signal power at 308 nm from the experiments. This determination yielded $P_3 = 3.5 \mu\text{W}$, or 26% of the theoretical value. The lower as expected power is likely due to non-ideal beam overlap and eventual slight mis-orientation of the crystal, leading to less than ideal phase matching and corresponding losses (overestimation of G_{SFG}).

Wavelength stability and tuning range



We have investigated wavelength stability and accuracy over the target tuning range between 307.8 nm and 308.2 nm. The graphs indicate the stability of the emission wavelengths over a typical time scale of several minutes for each source. Note that wavelengths have been measured consecutively. The Table summarizes the wavelength measurements using a WS7-60-UV1 wavelength meter (HighFinesse).

Target / nm	λ BL / nm	λ IR / nm	λ UV / nm	$\Delta\lambda$ UV / 10^{-4} nm
307.83406	441.69239	1015.76012	307.83406	0.0
307.90108	441.69251	1016.48969	307.90102	0.6
308.00067	441.69251	1017.57592	308.00058	0.9
308.13737	441.69251	1019.06948	308.13736	0.1
308.20308	441.69251	1019.78861	308.20304	0.4

Calculated (from SFG) and measured UV vacuum wavelengths agree to better than 10^{-4} nm over the target range at a measurement uncertainty between 2 and 4 10^{-5} nm. As can be seen from the graphs, a 10^{-4} nm wavelength instability is observed during the UV measurements (bottom figure). This is likely dominated by the stability of the ECDL (top figure).

Outlook

We have confirmed that our laser source covers the target wavelength range between 307.8 nm and 308.2 nm with sufficient power. Presently, we are working on the optimization and software control of this source. As a next step, we will integrate the laser into an existing vacuum system for the production of ozone for quantitative measurements of the ozone absorption cross section around 308 nm.

At the same time, we are collaborating with the LP2N for a 2nd laser source, based on the SFG of two infrared laser sources followed by frequency doubling in a cavity to reach the 308 nm to 318 nm range.

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